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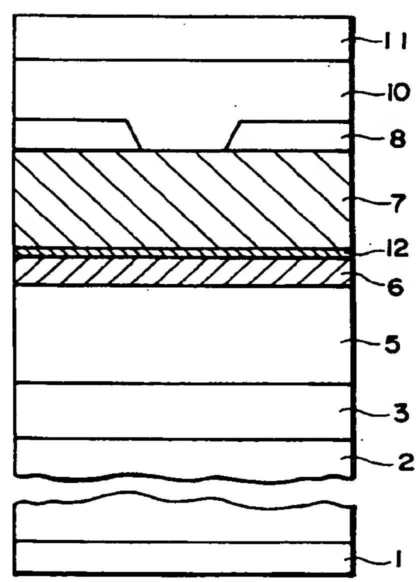
(54) Semiconductor laser.

(57) A p-type clad layer (7) constituting the semiconductor laser device according to this invention includes an inner clad area near to an active layer (6), and an outer clad area remote from the active layer (6), the outer clad area having a narrower bandgap than that of the inner clad area, the thickness and the composition of the inner clad area being so set that beams do not substantially exude from the active layer to the outer clad area. A multi-quantum barrier structure (12) is provided between the active layer (6) and the p-type clad layer (7). At least one of barrier layers of the multi-quantum barrier structure (12) is formed of material which applies tensile stress thereto, and at least one of the well layers provided between one of the barrier layers and its adjacent one is formed of a material which applies contraction stress thereto, whereby an average lattic constant of the multi-quantum barrier agrees with that of a substrate (2). The us of a material in the barrier layers allows the bandgap to be sufficiently wide. Consequently, ev n in comparatively high-temperature environments carriers, especially lectrons, can be prevented from ov rflowing from the active layer (6) to the clad layer (7), and no deterioration of the characteristics takes place.

Fig.5



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tunnel effect. A thinner inner layer has an advantage of a smaller series resistance. The inner layer usually has a thickness of about 100 Å, but the range of 50 - 200 Å is sufficient. The inner clad area may have a composition which has tensile stress with respect to the active layer, whereby a higher barrier can be formed. The Al composition ratio of the outer clad area may be made low, whereby the resistivity of the outer clad area can be low, and the series resistance of the p-clad layer as a whole can be made comparatively easily small.

In the semiconductor laser device according to a second invention, a barrier structure is formed between an active layer and a p-type clad layer, and the barrier structure is formed of a material which has tensile stress with respect to the active layer and the p-type clad layer.

By forming the barrier structure of a material which has tensile stress with respect to the active layer and the p-type clad layer, the bandgap can be wide. Consequently the overflow of carriers, especially electrons, from the active layer to the clad layer can be more efficiently prevented. But it is preferable that an amount of the distortion caused in the barrier structure, and a thickness of the barrier structure has values which can prevent dislocations. The barrier structure may be of a single-barrier layer or multi-barrier layers. In the multi-barrier layer-barrier structure, a material which is feasible to contraction stress is provided at an narrow bandgap area between one of the barrier layers and its adjacent one, whereby distortion which is counter to the distortion of the barrier layers can be caused, and distortion as a whole can be mitigated. Conveniently in this case, a distortion amount as a whole can be decreased also by increasing a distortion amount per one barrier layer, i.e., increasing an effective height of the barrier layer.

The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not to be considered as limiting the present invention.

Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art form this detailed description.

Brief Description of the Drawings

FIG. 1 is a sectional view of an embodiment of the visible semiconductor laser device according to a first aspect of the invention;

FIG. 2 shows views of an Al composition ratio of a clad layer of the visible semiconductor laser device according to the first aspect of the invention, and of a carrier density of the p-type clad layer thereof;

FIG. 3 shows views of a variation of the Al composition ratio of the clad layer of the visible semiconductor laser device according to the first aspect of the invention;

FIG. 4 shows views of a variation of the Al composition ratio of the clad layer of the visible semiconductor laser device according to the first aspect of the invention;

FIG. 5 is a view of the visible semiconductor laser device according to a second aspect of the invention;

FIG. 6 is a view of an energy band near an active layer of the visible semiconductor laser device according to one embodiment of the second aspect of the invention; and

FIG. 7 is a view of an energy band near an active layer of the visible semiconductor laser device according to another embodiment of the second aspect of the invention.

Description of the Preferred Embodiments

FIG. 1 is a sectional view of the semiconductor laser device according to a first aspect of the invention. In the laser device of FIG. 1, an n-type buffer layer 3 of, e.g., GaAs is formed on the top surface of a substrate 2 of, e.g., GaAs with an n-type electrode 1 formed on. On this buffer layer 3 there are formed an n-type clad layer 5, an active layer 6 and a p-type clad layer 7 in the stated sequence. The n-type clad layer 5 is formed of n-type AlGaInP of a uniform Al composition ratio, and the active layer 6 is formed of non-doped GaInP. The p-type clad layer 7 is formed of p-type AlGaInP. Both clad layers 5, 7 have a higher refractive index than the active layer 6.

On the p-type clad layer 7 an n-type semiconductor layer 8 of, e.g., GaAs is patterned to form a current limiting structure. On the n-type semiconductor layer 8 there are formed a p-type contact layer 10 of e. g., GaAs, and a p-type electrode 11 in the stated sequence.

Next with reference to FIG. 2, an Al composition ratio X of the p-type clad layer 7, and a carrier density distribution thereof characterizing this invention will be explained.

A part (a) of FIG. 2 shows a part of a section of the semiconductor laser device of FIG. 1, and Parts (b) and (c) of FIG. 2 respectively show Al composition ratios x and carrier densities resp ctively taken

position ratio in an area remote from the active layer 6. Otherwise completely different composition distributions are also possible.

As described above, according to the visible semiconductor laser device according to the first aspect of the invention, the inner clad area adjacent to the active layer has a wider bandgap, and carriers can be efficiently confined in the active lay r, and the outer clad area can have a comparatively low resistivity. Thus, a visible semiconductor laser device which can efficiently confine carriers in the active layer, and has small series resistances and small heat generation amounts can be provided.

FIG. 5 is a sectional view of the visible semiconductor laser device according to another embodiment of this invention. In comparison with the embodiment of FIG 1, a difference of this embodim nt is that a multi-quantum barrier structure 12 is provided between the active layer 6 and the p-type clad layer 7. The embodiment of FIG. 5 is the same as that of FIG. 1 in the n-type electrode 1, the substrate 2, the buffer layer 3, the n-type semiconductor layer 8, the contact layer 10 and the p-type electrode 11.

FIG. 6 is an energy band diagram of the semiconductor laser device according to the embodiment of FIG. 5 near the active layer. The solid line 100 indicates a conductor band level. In this semiconductor laser device the substrate is a GaAs substrate, the active layer 6 is formed of undoped $(Al_{0.2}Ga_{0.8})_{0.5}In_{0.5}P$, the n-type clad layer 5 is formed of n-type $(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$, and the p-type clad layer 7 is formed of p-type$(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$. The multi-quantum barrier structure 12 is formed of p-type $(Al_{0.7}Ga_{0.3})_{0.6}In_{0.4}P$ as barrier layers 13, and p-type $(Al_{0.7}Ga_{0.3})_{0.4}In_{0.6}P$ as well layers 14.

According to this embodiment, the barrier layers 13 are formed of a material having a wide bandgap, and the outflow of carriers from the active layer 6 to the p-type clad layer 7 can be effectively prevented. But on the other hand, this material does not lattice-match with the GaAs substrate, and the barrier layers 13 are under tensile stress. Even if a thickness of each barrier layer 13 is below a critical film thickness, dislocations may occur unless any countermeasure is taken. As a countermeasure, in this embodiment the well layers are formed of a material which has distortion exerted in a direction opposite to the tensile stress applied to the barrier layers 13, so that an average lattice constant of the barrier layers 13 and the well layers 14, i.e., a lattice constant of the multi-quantum barrier structure 12, agrees with that of the substrate for the lattic matching therebetw en. Accordingly no dislocations tak place. In the case that a material containing Al in a large amount that allows the barriers to be rais d with the lattice-matching secured is used as has been done conventionally, it is difficult to add p-type dopant impurities (usually Zn). But in this embodiment where the barriers are raised with the Al composition ratio kept comparatively low, the doping is easy. What have to be noted in designing the film thickness of the barrier layers 13 and that of the well layers 14 are that a thickness of each layer is below a critical film thickness for the distortion of the layer so as to prevent the generation of dislocations, and that the effect of the barrier structure against electrons is maximized as much as possible within a dislocation preventive range.

The respective layers of the semiconductor laser device according to this embodiment can be formed by OMVPE (Organic Metallic Vapor Phase Epitaxy). What has to be noted in forming the layers, the growth conditions are so set that diffusion of p-type dopants (usually Zn) does not damage the multi-quantum barriers. According to experiments made by the inventors, in the case that the layers were grown by OMVPE at 700 °C with a feed ratio between Zn and a III Group raw material set at 1, the multi-quantum barrier was left undamaged in about 70 Å, and there was no problem.

In this embodiment, the barrier layers 13 are formed of p-type $(Al_{0.7}Ga_{0.3})_{0.6}In_{0.4}P$, and the well layers 14 are formed of p-type $(Al_{0.7}Ga_{0.3})_{0.4}In_{0.6}P$. To be general, the effect of this invention can be achieved in the case that $1 \geq b > 0.5 \geq d \geq 0$ when the barrier layers 13 are formed of p-type $(Al_aGa_{1-a})_bIn_{1-b}P$, and the well layers 14 are formed of p-type $(Al_cGa_{1-c})_dIn_{1-d}P$. The subscripts a and c are usually $1 \geq a \geq c \geq 0$, but when a distortion amount is sufficiently large, $a<c$ is possible. Composition ratios (subscripts a, b, c, and d) of the respective barrier layers, and those of the well layers may be respectively different from one another. Conditions for preventing occurrences of dislocations may be experimentally determined in accordance with these constants.

In the above-described embodiment, the barrier to electrons is multi-quantum barriers structure but is not essentially quantum barriers. In place of the multi-quantum barrier structure, for example, a multi-barrier structure having no quantum effects is proposed. The structure includes three 70 Å-thickness barrier layers of $(Al_{0.7}Ga_{0.3})_{0.57}In_{0.43}P$, and 50 Å-thickness layers of $(Al_{0.7}Ga_{0.3})_{0.52}In_{0.48}P$ interposed between one of the barrier layers and its adjacent one, the layers having a smaller bandgap than the barrier layers.

The barrier structure for electrons may be of a singl layer. As shown in FIG. 7 for example, on 100 Å-thickness layer of $Al_{0.57}In_{0.43}P$ may be interposed betw en an active layer and a p-type clad lay r.

The semiconductor las r devic according to

Fig. 1

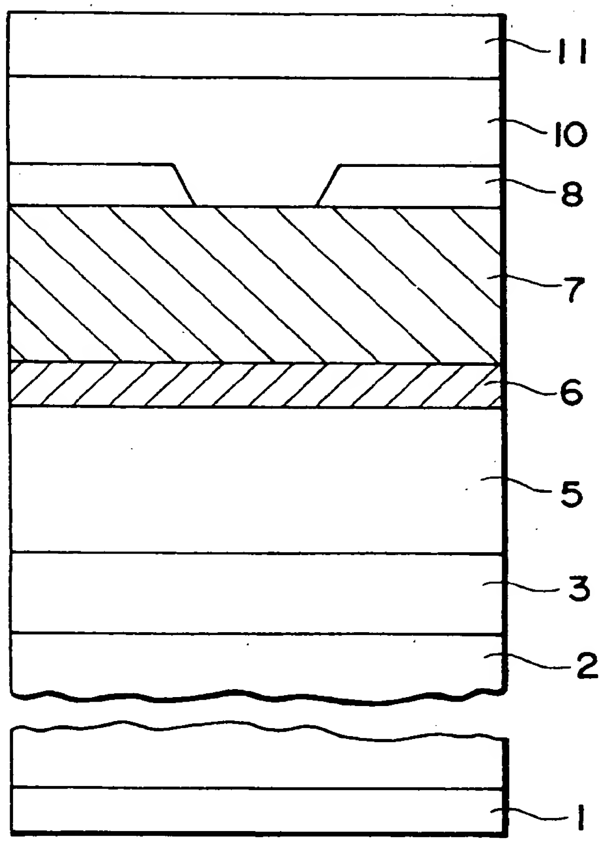

Fig. 3

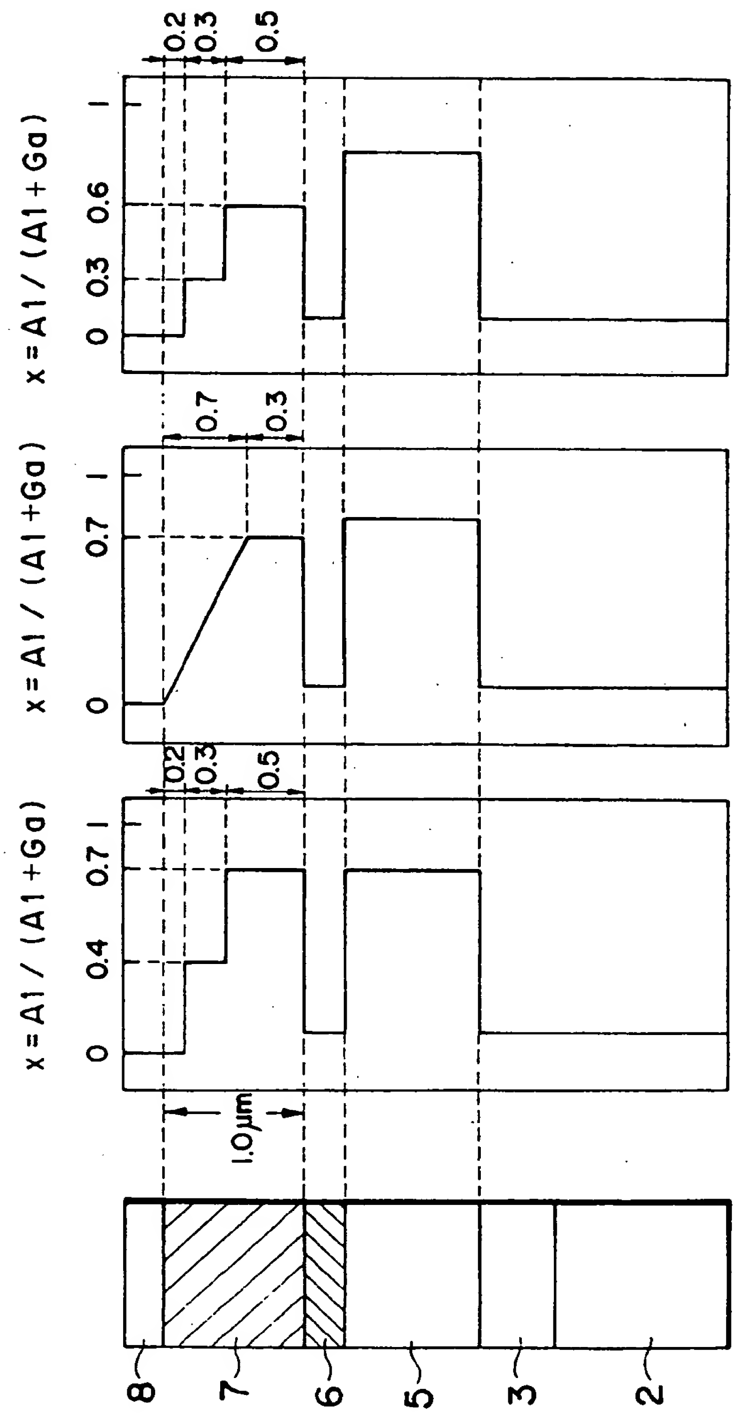
x = Al / (Al + Ga)
0
0.3
0.6
1
0.2
0.3
0.5
(d)
x = Al / (Al + Ga)
0
0.7
1
0.7
0.3
(c)
x = Al / (Al + Ga)
0
0.4
0.7
1
0.2
0.3
0.5
(b)
1.0μm
(a)
8
7
6
5
3
2

Fig. 5

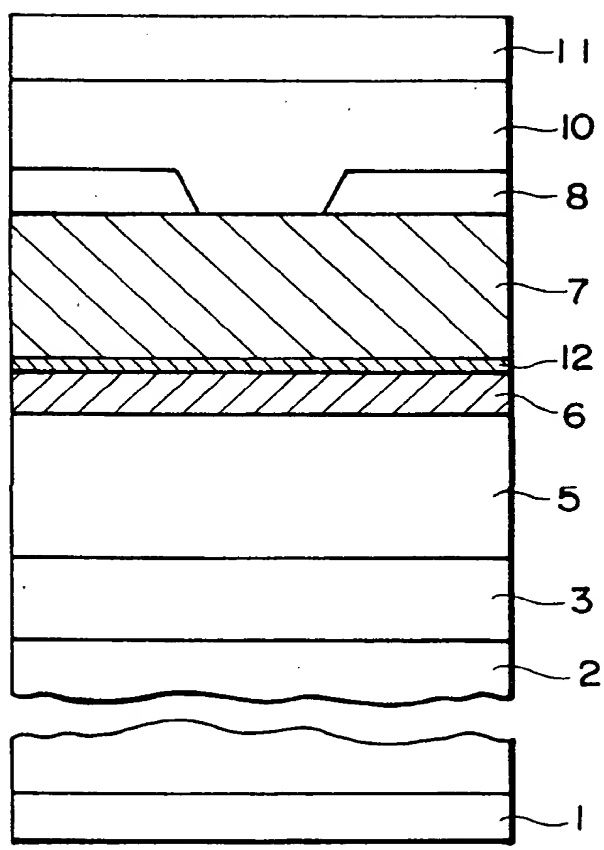

Fig. 1

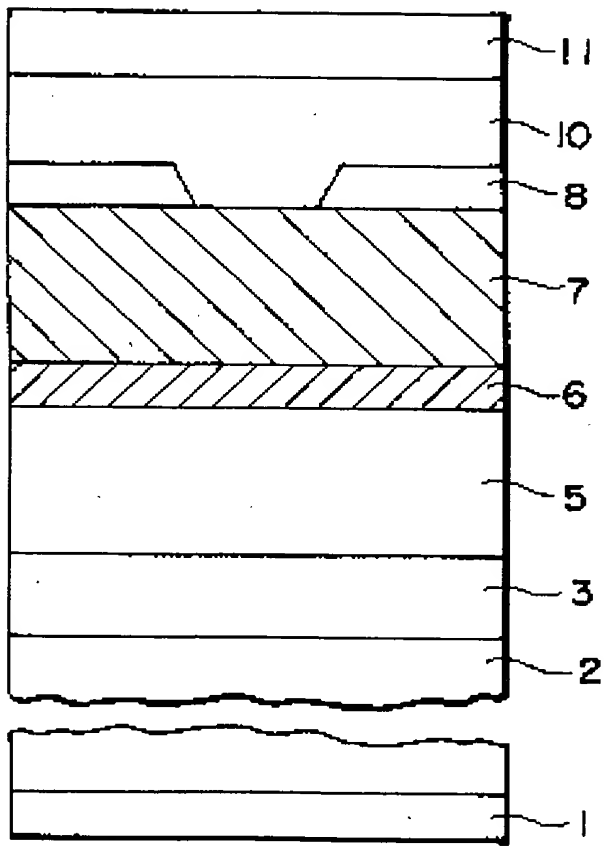

Fig. 3

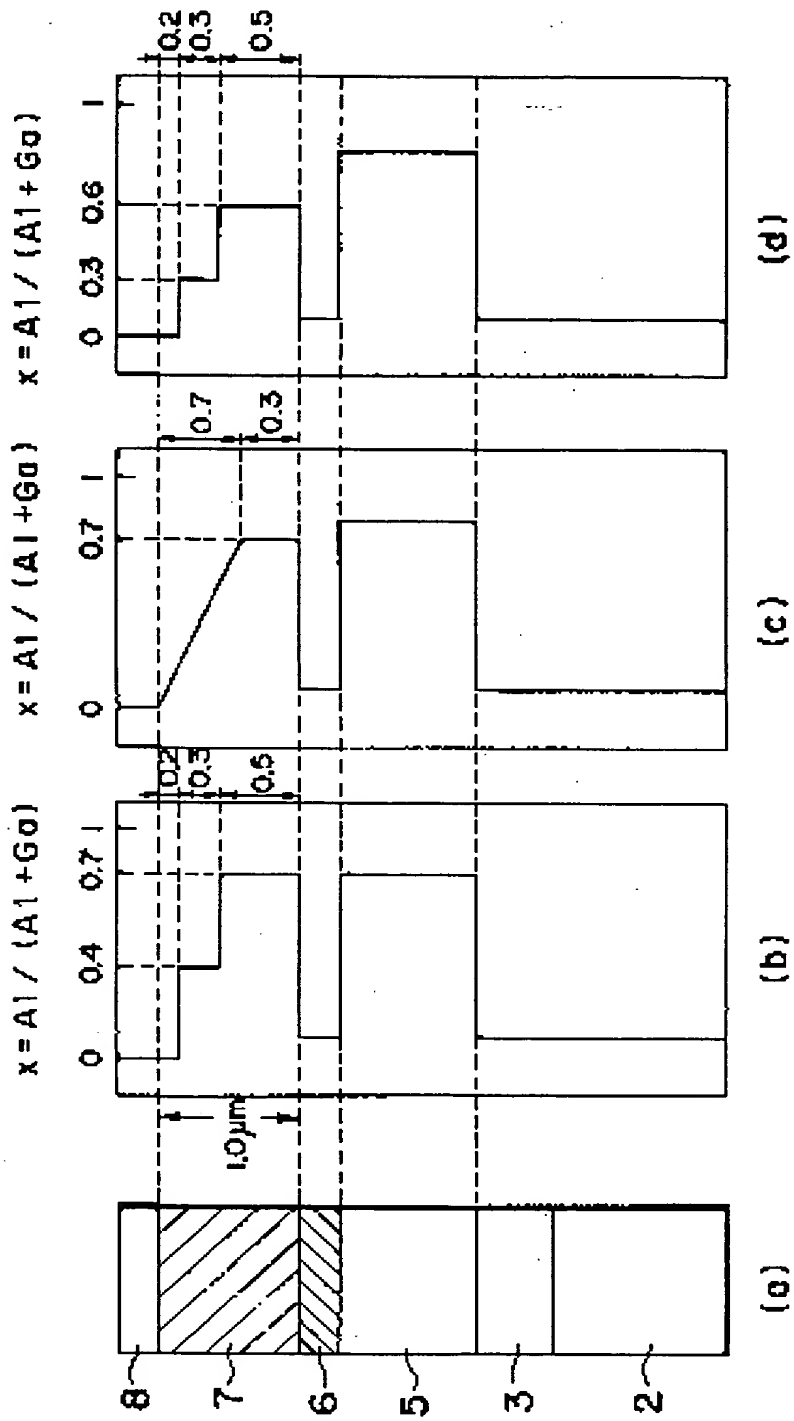

Fig. 5

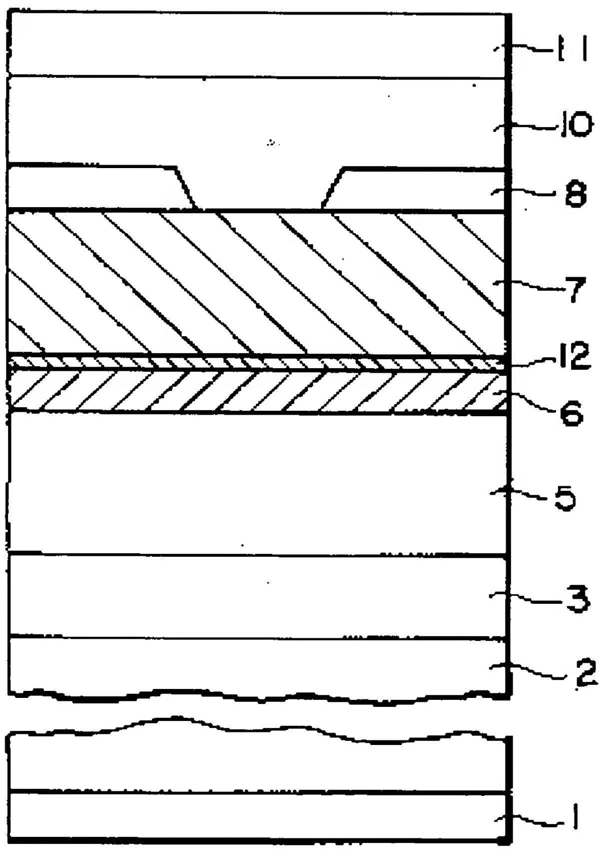

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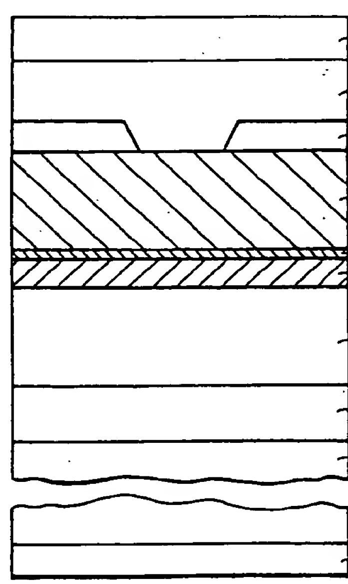
Fig.5



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CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing more than ten claims.

- ☐ All claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for all claims.
- ☐ Only part of the claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid,

  namely claims:
- ☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions,
namely:

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- ☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.
- ☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid.

  namely claims:
- ☐ None of the further search fees has been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims.

  namely claims:

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LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions, namely:

1. Claims 1-5 : Semiconductor laser comprising inner- and outer cladding layers. Said inner cladding layer having a bandgap which is in excess of the bandgap of said outer cladding layer, and being very thin in order not to confine light exuding from the active layer.

2. Claims 6-11 : A semiconductor laser device comprising a tensilelly strained barrier structure between active layer and cladding layers.